

CLAIMS

What is claimed is:

- 1 1. A method of estimating a property of interest relating to an earth formation
2 comprising:
 - 3 (a) conveying a Nuclear Magnetic Resonance (NMR) logging tool into a
4 borehole in said earth formation;
 - 5 (b) applying a first pulse sequence having a first associated measurement
6 frequency and measuring first NMR signals corresponding to said first
7 pulse sequence, said first NMR signals including non-formation signals
8 resulting from an excitation pulse and a refocusing pulse in said first pulse
9 echo sequence;
 - 10 (c) applying a plurality of additional pulse sequences having associated
11 additional frequencies different from each other and from said first
12 frequency;
 - 13 (d) measuring additional NMR signals resulting from applying said plurality
14 of additional pulse sequences; and
 - 15 (e) determining from said first and said additional measured NMR signals a
16 value of said property of interest, said value substantially unaffected by
17 said non-formation signals.
- 18

$$nf \cdot \delta f = \frac{2}{TE} = \frac{1}{TE/2}$$

where nf is the number of frequencies, δf is a separation of frequencies and TE is an interecho spacing.

7. The method of claim 5 wherein said first and said additional frequencies are related by an expression of the form:

$$nf \cdot \delta f = \frac{1}{TE}$$

where nf is the number of frequencies, δf is a separation of frequencies and TE is an interecho spacing.

8. The method of claim 1 wherein at least one of said first pulse sequence and said additional pulse sequences comprises a modified CPMG sequence having a refocusing pulse with a tipping angle of less than 180° .

9. The method of claim 8 wherein said first and said additional frequencies are related by an expression of the form:

$$nf \cdot \delta f = \frac{2}{TE} = \frac{1}{TE/2}$$

where nf is the number of frequencies, δf is a separation of frequencies and TE is an interecho spacing.

10. The method of claim 8 wherein said first and said additional frequencies are related by an expression of the form:

3
$$nf \cdot \delta f = \frac{1}{TE}$$

4 where nf is the number of frequencies, δf is a separation of frequencies and TE is
5 an interecho spacing.

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1 11. The method of claim 1 wherein determining the value of said property of interest
2 further comprises summing said first and said additional measured signals.

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1 12. The method of claim 1 wherein said first and said additional signals have a signal
2 loss of less than 0.8% relative to a signal that would be obtained at a nominal
3 frequency corresponding to said first and said additional frequencies.

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1 13. The method of claim 1 wherein the property of interest is at least one of (i) a T_2
2 distribution, (ii) a T_1 distribution, (iii) a porosity, (iv) a bound fluid volume, and
3 (v) a bound volume irreducible.

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1 14. The method of claim 1 wherein said first and said plurality of additional
2 frequencies are discretely sampled and wherein determining said value of said
3 parameter of interest further comprises forming a weighted summation of said
4 measurements at said first and said additional frequencies.

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1 15. The method of claim 14 wherein said forming of said weighted summation further
2 comprises minimizing a noise in an echo measurements.

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1 16. A Nuclear Magnetic Resonance (NMR) apparatus for use in a borehole in
2 proximity to an earth formation comprising:

3 (a) a magnet for producing a static field in a region of said earth formation,
4 said magnet aligning nuclear spins in said region substantially parallel to a
5 direction of said static field;

6 (b) a transmitter for applying radio-frequency pulse sequences at at each of at
7 least three different frequencies;

8 (c) a receiver for receiving at least three signals resulting from said at least
9 three pulse sequences, said at least three signals comprising the results of
10 interactions with the earth formation and with a non-formation; and

11 (d) a processor for determining from said at least three received signals a
12 value corresponding to a property of interest of said earth formation, said
13 value substantially unaffected by the interactions with said non-formation.

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1 17. The apparatus of claim 16 wherein said at least three frequencies are related by an
2 expression of the form:

3
$$nf \cdot \delta f = \frac{2}{TE} = \frac{1}{TE/2}$$

4 where nf is the number of frequencies, δf is a separation of frequencies and TE is
5 an interecho spacing.

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1 18. The apparatus of claim 16, wherein at least three frequencies are related by an
2 expression of the form:

3
$$nf \cdot \delta f = \frac{1}{TE}$$

4 where nf is the number of frequencies, δf is a separation of frequencies and TE is a
5 interecho spacing.

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1 19. The apparatus of claim 16, wherein phases of said non-formation signals resulting
2 from said at least three pulse sequences are substantially evenly distributed
3 around a unit circle.

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1 20. The apparatus of claim 16 wherein at least one of said three pulse sequences
2 comprises a CPMG sequence.

1 21. The apparatus of claim 20 wherein said at least three frequencies are related by an
2 expression of the form:

3
$$nf \cdot \delta f = \frac{2}{TE} = \frac{1}{TE/2}$$

4 where nf is the number of frequencies, δf is a separation of frequencies and TE is
5 an interecho spacing.

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1 22. The apparatus of claim 20, wherein at least three frequencies are related by an
2 expression of the form:

3
$$nf \cdot \delta f = \frac{1}{TE}$$

where nf is the number of frequencies, δf is a separation of frequencies and TE is a interecho spacing.

22. The apparatus of claim 16 wherein at least one of said at least three pulse sequences comprises a modified CPMG sequence having a refocusing pulse with a tipping angle less than 180° .

24. The apparatus of claim 23 wherein said at least three frequencies are related by an expression of the form:

$$nf \cdot \delta f = \frac{2}{TE} = \frac{1}{TE/2}$$

where nf is the number of frequencies, δf is a separation of frequencies and TE is an interecho spacing.

25. The apparatus of claim 23, wherein at least three frequencies are related by an expression of the form:

$$nf \cdot \delta f = \frac{1}{TE}$$

where nf is the number of frequencies, δf is a separation of frequencies and TE is a interecho spacing.

26. The apparatus of claim 16 wherein said processor determines said value by summing said at least three received signals.

1 27. A system for estimating a property of interest of an earth formation comprising:
2 (a) a logging tool including a magnet for producing a static field in a region of
3 said earth formation, said magnet aligning nuclear spins in said region
4 substantially parallel to a direction of said static field;
5 (b) a transmitter on said logging tool for applying radio frequency pulse
6 sequences at each of at least three frequencies;
7 (c) a receiver on said logging tool for receiving signals resulting from
8 interaction of said at least three pulse sequences with said earth formation,
9 said signals indicative of a property of said earth formation, said signals
10 including non-formation signals resulting from an excitation pulse and a
11 refocusing pulse in said at least three pulse sequences;
12 (d) a conveyance device for conveying said logging tool into a borehole in
13 said earth formation;
14 (e) a processor in electrical communication with the transmitter and the
15 receiver, said processor programmed to perform steps for determining
16 from said at least three received signals a value of a property of said earth
17 formation, said determined value of said property substantially unaffected
18 by said non-formation signals.

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1 28. The system of claim 27 wherein said conveyance device comprises a wireline.

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1 29. The system of claim 27 wherein said conveyance device comprises a drillstring.

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1 30. The system of claim 27 wherein said conveyance device comprises coiled tubing.

1 31. The system of claim 27 wherein said processor is programmed to select the at
2 least three frequencies according to an expression of the form:

3
$$nf \cdot \delta f = \frac{2}{TE} = \frac{1}{TE/2}$$

4 where nf is the number of frequencies, δf is a separation of frequencies and TE is
5 an interecho spacing.

6
1 32. The system of claim 27 wherein said processor is at a surface location.

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1 33. The system of claim 27 wherein said processor is at a downhole location.

2
1 34. The system of claim 27 wherein the processor is programmed to instruct the
2 transmitter to transmit at least one of said at least three pulse sequences as a
3 CPMG sequence.

4
1 35. The system of claim 27 wherein the processor is programmed to instruct the
2 transmitter to transmit at least one of said at least three pulse sequences as a
3 modified CPMG sequence having a refocusing pulse with a tipping angle less
4 than 180°.

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1 36. The system of claim 27 wherein said processor is programmed to determine said
2 value by summing said at least three received signals.

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1 37. The system of claim 27 wherein said property is at least one of (i) a T_2
2 distribution, (ii) a T_1 distribution, (iii) a porosity, (iv) a bound fluid volume,
3 and, (v) a bound volume irreducible.

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1 38. The system of claim 27 wherein said processor is at a surface location

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1 39. The system of claim 27 wherein said processor is at a downhole location.

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